(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
19 July 2001 (19.07.2001)

PCT

(10) International Publication Number
WO 01/51730 A1

(51) International Patent Classification[7]: E04C 5/07

(21) International Application Number: PCT/US01/00533

(22) International Filing Date: 8 January 2001 (08.01.2001)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/175,896 13 January 2000 (13.01.2000) US

(71) Applicant: THE DOW CHEMICAL COMPANY [US/US]; 2030 Dow Center, Midland, MI 46874 (US).

(72) Inventors: EDWARDS, Christopher, Michael; 2613 Hearthstone Circle, Midland, MI 48642 (US). D'HOOGHE, Edward, L.; Steensedijk 56, NL-4561 GN Hulst (NL).

(74) Agent: WILLIS, Reid, S.; Intellectual Property, P.O. Box 1967, Midland, MI 48641-1967 (US).

(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, UZ, VN, YU, ZA, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

WO 01/51730 A1

(54) Title: REINFORCING BARS FOR CONCRETE STRUCTURES

(57) Abstract: Reinforcing bars for concrete structures, are made from a composite of a depolymerizable and repolymerizable thermoplastic resin ad longitudinally oriented reinforcing fibers. These reinforcing bars provide excellent tensile reinforcement, and do not exhibit the corrosion problems of conventional steel reinforcing bars. The rebars are readily formed into a great many shapes that are adapted to many specialized reinforcement requirements.

REINFORCING BARS FOR CONCRETE STRUCTURES

The research and development leading to the subject matter disclosed herein was not federally sponsored.

This invention relates to reinforcing materials for concrete and concrete structures so reinforced.

Concrete is one of the most common building materials. It is used in a wide variety of structures such as bridges, walls, floors, building supports, roadways, and runways among many others.

Concrete has excellent compressive strength, but is very poor in tensile strength. As a result, it is almost always necessary to reinforce a concrete structure if the structure will be exposed to tensile stresses such as those generated by a bending load. A very common way of providing this reinforcement is to incorporate metal (usually steel) reinforcing bars into the concrete. Steel reinforcing bars can provide a great improvement in tensile strength to the concrete structure.

Unfortunately, steel reinforcing bars corrode over time when exposed to water. This corrosion is accelerated if the steel is exposed to salts, as are often used in colder climates to melt snow and ice from the road surface. The concrete tends to provide some protection from water and salts, but over time cracks develop in the concrete and these materials are able to seep through the cracks to the embedded steel. As the steel begins to corrode, it expands due to the formation of rust layers. This expansion causes further cracking in the concrete, thereby accelerating the decay of the concrete structure.

To avoid this corrosion problem, certain pultruded composites have been tried. These composites include a thermoset resin that serves as a matrix into which longitudinal fibers, usually glass but sometimes of other materials, are embedded.

These thermoset composites solve the corrosion problem, but have other significant drawbacks. The most significant of these is that there is no practical way that these thermoset composites can be formed into a variety of shapes. Steel reinforcing bars are

commonly bent, twisted or formed into rings in order to accommodate them to the needs of a particular construction project. This is often done on-site, but can also be done as part of the rebar manufacturing process. Pultruded thermoset composites are not formable once the thermosetting resin matrix is cured. Thus, on-site forming is not an option with the thermoset composites. Even in-factory forming is difficult. The pultrusion process is mainly adapted for making straight composites of constant cross-section. Any forming that is done must take place during a brief time window between the time the resin is applied to the reinforcing fibers and cured to a viscosity that it will not run off and the time the resin is fully cured. This short time window makes forming very difficult and expensive to accomplish for a thermoset composite.

A second major shortcoming of thermoset composites is that they are difficult to key into the concrete. Steel rebars often have raised or indented sections that are molded or stamped onto the surface of the bar. These sections permit the bar to be mechanically interlocked into the concrete. Thermoset composites, on the other hand, usually have a constant cross-section due to the nature of the pultrusion process. Post-forming methods for providing surface features such as stamping are not suitable because the thermoset composites tend to be brittle and have poor impact resistance. The stamping process tends to break the embedded fibers and weaken the composite. Sometimes overmoldings are used to provide a raised surface for keying into the concrete. However, the bond between the overmolding and the composite is often weaker than the concrete matrix and thus provides little benefit.

In addition, thermoset composites suffer from poor elongation (on the order of 1 percent at break), poor impact resistance and brittleness. They also are quite expensive, mainly due to slow production rates.

It would therefore be desirable to provide an alternative to steel and thermoset composite reinforcing bars for concrete structures.

In one aspect, this invention is a reinforcing bar (rebar) comprising a composite of a plurality of longitudinally oriented reinforcing fibers embedded in a matrix of a thermoplastic resin.

The reinforcing bar of this invention solves many of the problems associated with steel and thermoset composite rebars. The rebar of this invention does not corrode due to exposure to water and/or common salts. The rebar of the invention is readily formed into a great many shapes and configurations. As a result, it is easily formed into shapes that enable it to key into concrete, forming a mechanical interlock with the concrete that improves the reinforcing effect. This forming can be done easily on-site if desired. The reinforcing bar of the invention is often capable of being manufactured at higher rates than pultruded thermoset composites. As a result, the rebar of the invention can be less expensive and perform better than thermoset composite rebars.

In a second aspect, this invention is a concrete structure comprising a reinforcing bar embedded in a concrete matrix, said reinforcing bar comprising a composite of a plurality of longitudinally oriented reinforcing fibers embedded in a matrix of a thermoplastic resin.

Figures 1A-1J, 2, 3A-3B and 4A-4C are isometric views of various embodiments of the invention.

The reinforcing bar of this invention comprises a composite of longitudinally oriented reinforcing fibers embedded in a matrix of a thermoplastic resin. It is conveniently made in a pultrusion process as described in U. S. Patent No. 5,891,560 to Edwards et al.

The reinforcing fiber can be any strong, stiff fiber that is capable of being processed into a composite through a pultrusion process. Suitable fibers are well known and are commercially available. Glass, other ceramics, carbon, metal or high melting polymeric (such as aramid) fibers are suitable. Mixtures of different types of fibers can be used. Moreover, fibers of different types can be layered or interwoven with the composite in order to optimize certain desired properties. For example, glass fibers can be used in the interior regions of the composite and stiffer, more expensive fibers such as carbon fibers used in the exterior regions. This permits one to obtain the benefits of the high stiffness of the carbon fibers while reducing the overall fiber cost. In addition, the exterior carbon fibers provide additional protection for the glass fibers from the alkaline environment in the cement.

Suitable fibers are well known and commercially available. Fibers having diameters in the range of about 10 to 50 microns, preferably about 15-25 microns, are particularly suitable.

By "longitudinally oriented", it is meant that the reinforcing fibers extend essentially continuously throughout the entire length of the composite, and are aligned in the direction of pultrusion.

For most applications, glass is a preferred fiber due to its low cost, high strength and good stiffness.

As it is the fibers that mainly provide the desired reinforcing properties, the fiber content of the composite is preferably as high as can conveniently be made. The upper limit on fiber content is limited only by the ability of the thermoplastic resin to wet out the fibers and adhere them together to form an integral composite without significant void spaces. The fibers advantageously constitute at least 30 volume percent of the composite, preferably at least 50 volume percent and more preferably at least 65 volume percent.

The thermoplastic resin can be any that can be adapted for use in a pultrusion process to form the composite, and which does not undesirably react with the reinforcing fibers. However, the thermoplastic resin preferably has additional characteristics. The thermoplastic resin preferably is a rigid polymer, having a T_g of not less than 50°C. In addition, the thermoplastic resin preferably forms a low viscosity melt during the pultrusion process, so as to facilitate wetting out the reinforcing fibers. The thermoplastic resin preferably does not react with concrete in an undesirable way and is substantially inert to (i.e., does not react with, absorb, dissolve or significantly swell when exposed to) water and common salts. Among the useful thermoplastics are the so-called "engineering thermoplastics", including polystyrene, polyvinyl chloride, ethylene vinyl acetate, ethylene vinyl alcohol, polybutylene terephthalate, polyethylene terephthalate, acrylonitrile-styrene-acrylic, ABS (acrylonitrile-butadiene-styrene), polycarbonate, polypropylene and aramid resins, and blends thereof.

A particularly suitable thermoplastic resin is a depolymerizable and repolymerizable thermoplastic (DRTP). Examples of these are rigid thermoplastic polyurethanes or polyureas (both referred to herein as a "TPUs"). TPUs have the property of partially

depolymerizing when heated due in part to the presence of residual polymerization catalyst. The catalyst is typically hydrolytically- and thermally-stable and is "live" in the sense that it is not inactivated once the TPU has been polymerized. This depolymerization allows the TPU to exhibit a particularly low melt viscosity, which enhances wet-out of the fibers. Upon cooling, the polyurethane repolymerizes to again form a high molecular weight polymer.

In addition, TPUs tend to form particularly strong adhesive bonds to concrete, compared to those formed by less polar resins such as polypropylene.

Suitable thermoplastic polyurethanes are described, for example, in U. S. Patent No. 4,376,834 to Goldwasser et al. Fiber-reinforced thermoplastic composites suitable for use in the invention and which are made using such rigid TPUs are described in U. S. Patent No. 5,891,560 to Edwards et al.

The composites described in U. S. Patent No. 5,891,560 include a continuous phase which is advantageously a polyurethane or polyurea (or corresponding thiourethane or thiourea) impregnated with at least 30 percent by volume of reinforcing fibers that extend through the length of the composite. The general pultrusion process described in U. S. Patent No. 5,891,560 includes the steps of pulling a fiber bundle through a preheat station a fiber pretension unit, an impregnation unit, a consolidation unit that includes a die which shapes the composite to its finished shape, and a cooling die. The pulling is advantageously accomplished using a haul off apparatus, such as a caterpillar-type haul off machine. Additional shaping or post-forming processes can be added as needed.

As described in U. S. Patent No. 5,891,560, the preferred continuous phase polymer is a thermoplastic polyurethane or polyurea made by reacting approximately stoichiometric amounts of (a) a polyisocyanate that preferably has two isocyanate groups per molecule, (b) a chain extender, and optionally (c) a high equivalent weight (i.e., above 700 to about 4000 equivalent weight) material containing two or more isocyanate-reactive groups. By "chain extender", it is meant a compound having two isocyanate-reactive groups per molecule and a molecular weight of up to about 500, preferably up to about 200. Suitable isocyanate-reactive groups include hydroxyl, thiol, primary amine and secondary amine groups, with

hydroxyl, primary and secondary amine groups being preferred and hydroxyl groups being particularly preferred.

Preferred TPUs are rigid, having a glass transition temperature (T_g) of at least 50°C and a hard segment content (defined as the proportion of the weight of the TPU that is made up of chain extender and polyisocyanate residues) of at least 75 percent. Rigid thermoplastic polyurethanes are commercially available under the trade name ISOPLAST® engineering thermoplastic polyurethanes. ISOPLAST is a registered trademark of The Dow Chemical Company.

"Soft" polyurethanes having a T_g of 25°C or less can be used, but tend to form a more flexible composite. Thus, "soft" polyurethanes are preferably used as a blend with a rigid thermoplastic polyurethane. The "soft" polyurethane is generally used in a proportion sufficient to increase the elongation of the composite (in the direction of the orientation of the fibers). This purpose is generally achieved when the "soft" polyurethane constitutes 50 percent or less by weight of the blend, preferably 25 percent or less.

The preferred DRTP can be blended with minor amounts (i.e., 50 percent by weight or less) of other thermoplastics, such as polystyrene, polyvinyl chloride, ethylene vinyl acetate, ethylene vinyl alcohol, polybutylene terephthalate, polyethylene terephthalate, acrylonitrile-styrene-acrylic, ABS (acrylonitrile-butadiene-styrene), polycarbonate, polypropylene and aramid resins. If necessary, compatibilizers can be included in the blend to prevent the polymers from phase separating.

The fiber-reinforced composite is formed into a rebar. In general, the rebar has a high aspect ratio (ratio of length to largest cross-sectional dimension). Aspect ratios of about 20 to 250 are common. The largest cross-sectional dimension of the rebar will of course vary considerably depending on the particular structure being reinforced. Typically, the largest cross-sectional dimension will range from ¼ inch to three inches or more (0.6 cm to 7.5 cm), and more typically range from about ½ inch to about 2 inches (1.2 cm to about 5 cm).

The rebar is also preferably shaped with some curvature, bending and/or variation of its cross-section along its length, so as to be capable of mechanically interlocking with the concrete. This shaping can be done on-line as part of the process of forming the rebar

or can be done in some subsequent operation, including an on-site operation. Because the composite is readily formable, the rebar of the invention can assume a wide variety of configurations. Some of those configurations are exemplified in Figures 1A-1J.

One way to provide for mechanical keying into the concrete is to form a spiraled rebar having any non-circular cross-section. Figure 1A and 1B illustrate this concept. In Figures 1A and 1B, reinforcing bars 1 and 1A have, respectively, star-shaped and square cross-sections in which the orientation of the cross-sectional shape spirals along the length of the rebar. Because the spiraled cross-section is not circular, rebars 1 and 1A have surfaces that undulate along the length of the rebars, as shown by reference numerals 2 and 2A in Figure 1A and reference numerals 3 and 3A in Figure 1B. The undulating surface provides for mechanical interlocking with the concrete. This effect can be obtained by pultruding any cross-sectional shape except a circle, and either twisting the pultruded mass after it exits the die or rotating the die during the pultrusion process. Thus, the cross-section can be, e.g., an ellipse, an oval or any regular or irregular polygon. It is also possible, and sometimes preferable, to fabricate a spiraled rebar that comprises both left- and right-handed spirals.

Twisting two or more individual pultruded sections to form a thicker rebar can achieve a similar effect, as shown in Figure 1G. In Figure 1G, rebar 81 is made up of four smaller strands 82 of fiber reinforced composite, which are twisted together. The twisting step can be performed on-line during the pultrusion step, while the thermoplastic resin is still at a temperature such that the pultruded strands 82 can be thermoformed. Alternatively, strands 82 can be re-heated and twisted to form rebar 81 separately from the pultrusion process. The number of smaller strands can of course vary considerably, e.g. from 2 to 12 or more, depending on the desired thickness of rebar 81 and that of the individual strands 82. Another way of achieving a similar rebar is to braid or weave, rather than to simply twist, individual strands 82.

Figure 1B shows another optional feature, hole 4 that traverses the length of reinforcing bar 1A to form a hollow piece. Hole 4 can be provided, for example, to produce a lighter weight reinforcing bar that has a greater surface area to cross-section ratio, which would be advantageous where greater chemical keying of the surface to the

concrete is important. A hollow reinforcing bar of this type can be heated and easily crimped in order to bend it or to provide surface irregularities for mechanical interlocking into the concrete. Alternatively, hole 4 can be filled with various materials in order to achieve particular desired product characteristics. For example, hole 4 can be filled with a thermoplastic or thermoset resin, such as off-spec or recycled resin, various fillers such as glass, magnetic, other metallic particles, wood, and ceramic or metallic (e.g., steel) rods.

Hollow rebars of the type shown in Figures 1B, 1C and 1J are easily prepared using a circular die in the consolidation unit of the pultrusion process. Filler materials can be injection molded into the resulting hole when desired. Alternatively, the composite can be pultruded directly over a core of filler material.

A resinous matrix having short (preferably less than 2 inches (less than 5 cm), more preferably less than ½ inch (less than 1.3 cm) in length), randomly oriented reinforcing particles is a particularly suitable type of filler material, as it provides for omnidirectional strengthening of the rebar. Another preferred type of filler material is a metal, or a resinous or other matrix containing metal fibers or particles. It is often necessary to locate rebars in a concrete structure, as, for example, when repairs are to be made. Metallic filler materials enable the rebar to be detected using ordinary metal detectors, in the same way as steel rebars are currently located.

Another third preferred type of filler material is a resinous or other matrix containing magnetic particles. When exposed to a strong magnetic field, the magnetic particles will become heated. This provides a convenient method for softening the rebar for on-site forming. The heated magnetic particles transfer heat to the thermoplastic resin, thereby causing it to soften enough that the rebar can be formed into the required shape. Magnetic particles include barium ferrite and strontium ferrite, iron oxides such as Fe_3O_4 and Fe_2O_3, alloys of iron, aluminum, nickel, cobalt, copper, carbon, titanium, manganese, chromium, tungsten, platinum, silver, molybdenum, vanadium, or niobium or combinations thereof such as powdered alnico alloys, cunico alloys, chromium steel, cobalt steel, carbon steel, and tungsten steel. The size of the magnetizable particles is generally in the range of submicron to mm. A commercial example of a ferromagnetically filled thermoplastic is EMAWELD™ interlayer (a trademark of Ashland Chemical Co.).

As shown in Figure 1C, hole 24 may be filled only at preselected portions of its length in order to provide localized strengthening without unduly increasing weight. In Figure 1C, hole 24 extends longitudinally throughout the length of rebar 21. Filler material 25 fills the middle portion of hole 24, but hole 24 is otherwise unfilled. Filler material 25 thus provides increased shear strength at the center of the length of rebar 21, where the shear stresses are commonly the greatest. This embodiment of the invention is particularly useful as a dowel bar, as described below.

The rebar shown in Figure 1J illustrates another way to provide for mechanical interlocking with the concrete. In Figure 1J, rebar 91 has hole 92 and flattened areas 93 that are conveniently made by crimping or crushing. In addition to providing mechanical interlocking with the concrete, the flattened areas 93 provide spots at which rebar 91 can be more easily bent or shaped. As shown in Figure 1J, rebar 91 may be hollow, but that is not necessary.

Conversely, providing areas of increased cross-section as shown in Figure 1E can create mechanical interlocking with the concrete. Areas 38 of rebar 31 in Figure 1E have larger cross-sectional diameters than the remaining portions. This can be accomplished by overmolding a thermoplastic or thermoset resin onto the rebar, especially a resin containing randomly oriented reinforcing fibers. However, overmolding is a less preferred process because the adhesion of the overmold to the underlying composite is sometimes inadequate. Another way of accomplishing this is to employ a die of variable diameter in the pultrusion process. By periodically increasing the diameter of the die, areas of increased diameter can be formed on the rebar.

In Figure 1D, offset portions 47 of rebar 41 create mechanical interlocking with the concrete. This can be done by crimping or thermoforming the corners of a rebar having a polygonal cross-section. In Figure 1F, mechanical interlocking is created by introducing curves 59 into rebar 51. Curves 59 are shown as generally sinusoidal curves in Figure 1F, but localized curves, sharper bends and curves of other patterns are equally useful. In addition to providing sites for mechanically interlocking the rebar into the concrete, these curves tend to provide the rebar with somewhat increased elongation. When a load is

applied to a curved rebar, the rebar will not break until at least some of the applied force is dissipated in straightening the bar.

Figure 1H illustrates yet another way to provide raised surface features for interlocking with the concrete. In Figure 1H, rebar 71 has spiraled windings 75, which may be overmolded or pultruded onto the main body 72 of rebar 71. In a preferred embodiment, both the main body 72 and windings 75 are pultruded composites of a thermoplastic resin and longitudinal reinforcing fibers as described before. Rebar 71 is conveniently made by separately extruding main body 72 and windings 75 and wrapping windings 75 about main body 72 at an elevated temperature so that the windings are thermoformable and adhere to main body 72. Another way of making rebar 71 is to use a shaped, rotating die to make main body 72 and windings 75 together in a single step. A third way is to use a shaped but stationary die to make main body 72 and winding 75 in a single step, and then to twist the pultruded part, either on-line or in a separate process step.

Yet another way to provide for mechanical interlocking is to provide raised surface dimples as shown in Figure 1I. As shown, rebar 86 has a plurality of dimples 89 that protrude from the main surface. Again, this can be done in a variety of ways. A simple way is to partially embed a suitable particulate into the surface of reinforcing rebar 86 while the thermoplastic resin is in a softened state. Suitable particulates include thermoplastic or thermoset resins, glass or other ceramic materials, metal particles, sand and other minerals.

In another embodiment illustrated in Figure 2, rebar 201 according the invention includes core 203 and sheathing 202. Core 203 is suitably steel or other metal. Sheathing 202 is a composite of a thermoplastic resin and longitudinal reinforcing fibers as described before. The thickness of sheathing 202 relative to that of rebar 201 as a whole can vary according to the particular application in which it is used. A relatively thick core 203 provides rebar 201 with reinforcing properties very comparable to those of a conventional steel rebar, with the added benefit that sheathing 202 protects core 203 from exposure to water, salts and other corrosive materials. A relatively thinner core 203 provides less strength, but permits rebar 201 to be located in a concrete structure using conventional metal detectors.

The reinforcing bar of the invention is easily fabricated into complex reinforcing structures if desired. This can be achieved in a number of ways that take advantage of the thermoformability of the reinforcing member.

For example, Figure 3A illustrates reinforcing grid 301 made from individual small diameter composite strands 302 of a DRTP and longitudinal reinforcing fibers as described before. The individual strands 302 are easily formed into a unitary grid by heating strands 302 at their intersection points so that the thermoplastic becomes softened and cause the individual strands to adhere together. Alternatively, the individual strands 302 can be woven together, again by heating the individual strands 302 so that the DRTP becomes softened and the strands thus become somewhat flexible. Alternatively, the individual strands can be adhered together with a suitable adhesive, such as a hot melt adhesive. Less preferably, mechanical means can be used to assemble strands 302 into grid 301.

Figure 3B illustrates a shear truss or similar assemblage made from the rebar of the invention. Shear truss 310 consists of straight rebars 311 and 312 and serpentine rebar 313. Rebars 311, 312 and 313 are readily joined at their intersections through the use of adhesives, welding or through the use of any type of mechanical connectors. Molded connectors can be formed to hold the individual members together, if desired. These connectors or bridges can be formed from the same fiber-reinforced composite as are reinforcing bars 311, 312 and 313. Alternatively, the connectors or bridges can be made of a non-reinforced thermoplastic or thermosetting resin.

It will be apparent that in addition to shear truss 310 a large number of complex reinforcing structures can be prepared in an analogous manner, as needed for a particular job.

Fiber-reinforced rebars of the invention are easily fabricated to create integral connecting features. Figure 4A, for example, illustrates rebar 401 having terminal hooks 407 that can be used to connect rebar 401 to other rebars or other structural components. Alternatively, rebar 408 of the invention can have deformed ends 409 as shown in Figure 4B to facilitate anchoring the member through a wedging action.

Curves of the type illustrated in Figure 4A and deformations as illustrated in Figure 4B are conveniently introduced in a post-forming process by reheating the fiber-reinforced

composite to a temperature at which the thermoplastic resin softens, forming the softened composite into the desired shape, and then cooling the composite so that the thermoplastic rehardens. In like manner, looped rebars can be made, such as circular or elliptical rebars.

It will be noted that simply bending or curving a rebar of the invention will tend to cause a certain amount of fiber buckling or distortion. This is because the radius of curvature on the inside of the bend or curve is smaller than that of the outside of the curve. The bending or curving process therefore puts compressive stresses onto the fibers on the inside of the bend or curve and tensile stresses on those on the outside of the bend or curve. This problem can be largely or wholly overcome by twisting the composite as it is bent or curved. This permits all fibers to experience nearly the same tensile and compressive stresses, thereby reducing or eliminating the buckling or distortion. The orientation of the fibers in such a twisted and bent rebar is illustrated in Figure 4C. Rebar 410 includes fibers 411 that are twisted along the longitudinal extension of rebar 410. This enables all of fibers 411 to experience like compressive and tensile stresses. The longitudinal twisting also provides greater apparent ductility in the composite.

A specialized form of rebar that is used in some concrete structures is known as a dowel bar. A dowel bar is often used, for example, in concrete highways to connect adjoining concrete roadway surface panels. The dowel bar "bridges" the adjoining panels, with one end of the dowel bar being embedded in one of the panels and the other end embedded in the second of the panels. Unlike many other types of rebars, it is often desirable that the dowel bar is able to move with respect to the panels. In a highway, this permits the individual road panels to move slightly with respect to each other to accommodate thermal expansion and contraction.

The rebar of this invention is easily adapted to serve as a dowel bar. For use as a dowel bar, it is preferred that the bar does not mechanically interlock with the concrete, so dowel bars made in accordance with the invention preferably are straight pieces with uniform cross-section along their length. Because the preferred TPUs tend to adhere strongly to concrete, it is preferred to apply a coating that does not adhere well to concrete. A coating of any non-polar resin, such as polytetrafluoroethylene or polypropylene, is suitable for this purpose. As the dowel bar is subjected to the greatest shear forces at the

point where the adjoining concrete panels meet, the rebar of the invention can be further reinforced at the corresponding section of the rebar. This can be done, for example, by forming a hollow rebar in which the central core is filled near the middle of the length of the rebar, as shown in Figure 1C.

It will be appreciated that many other variations of the rebar of the invention can be made, according to the needs of a specific concrete structure in which it will be used. For example, the rebar may be mounted near the surface of the concrete by introducing a channel at the surface of the concrete and bonding the rebar into the channel. Such near surface mounted rods are useful in the upgrading and repair of existing structures.

The rebar of the invention is used in much the same manner as conventional steel rebars are used. The rebars are assembled into place, forming a skeleton or framework over which the concrete structure is formed. Individual rebars can be connected together in a variety of ways, including ties, clamps, welds, brackets, snap-on bridges or other connectors, glues, and the like, to hold them in place until the concrete is poured and hardens. In preferred embodiments, the concrete is poured over the skeleton or framework and permitted to harden.

As used herein, "concrete" is used in the usual sense of meaning a mixture of a particulate filler such as gravel, pebbles, sand, stone, slag or cinders in either mortar or cement. Suitable cements include hydraulic cements such as Portland cement, or aluminous cement. The cement or concrete may contain other ingredients such as, for example, a plastic latex, hydration aids, curatives, and the like.

The rebar of the invention can also be used as an external reinforcement for a variety of types of structures. Because the rebar is easily thermoformable, bends can be made near the ends of a rebar, forming, for example, a rectangular shaped rebar. Such a rebar can be keyed into the surface of structure by imbedding the ends into the structure. In this manner, reinforcement can be applied across existing cracks in a structure to slow or prevent further crack propagation.

In addition to or separate from rebars, composite "megafibers" can be dispersed into a concrete mix to provide reinforcement for the concrete. These megafibers, if sufficiently large, can provide the strength provided by the rebar, while at the same time

providing crack control that small fibers can provide.

CLAIMS:

1. A reinforcing bar comprising a composite of a plurality of longitudinally oriented reinforcing fibers embedded in a matrix of a thermoplastic resin.

2. The reinforcing bar of either of claims 1 or 2, wherein said thermoplastic resin is a depolymerizable and repolymerizable thermoplastic resin.

3. The reinforcing bar of claim 2 that is adapted to mechanically interlock into said concrete.

4. The reinforcing bar of claim 2, wherein said depolymerizable and repolymerizable thermoplastic resin includes a thermoplastic polyurethane or a thermoplastic polyurea having a T_g of not less than 50° C.

5. The reinforcing bar of any of claims 1-4, wherein said longitudinally oriented reinforcing fibers are continuous through the length of the reinforcing bar.

6. The reinforcing bar of any of claims 1-5, wherein said longitudinally oriented reinforcing fibers are glass or carbon fibers.

7. The reinforcing bar of any of claims 1-6, which has a non-circular cross-section and which contains at least one spiraled portion along the length of the rebar.

8. The reinforcing bar of any of claims 1-6, which is composed of a plurality of twisted, woven or braided strands of a composite of a depolymerizable and repolymerizable thermoplastic resin and longitudinally oriented reinforcing fibers.

9. The reinforcing bar of any of claims 1-6, which is curved or bent.

10. The reinforcing bar of any of claims 1-6, which has a polygonal cross section having corners, and at least one of said corners are deformed at a plurality of places along the length of said rebar.

11. The reinforcing bar of any of claims 1-6, which includes areas of increased cross-sectional area, relative to the cross-section of the remainder of the rebar.

12. The reinforcing bar of any of claims 1-11, which is hollow.

13. The reinforcing bar of any of claims 1-11, which has a longitudinal hole traversing its length, and at least a portion of said longitudinal hole is filled with a thermoplastic resin, a thermoset resin, magnetic particles, a ceramic, wood or a metal.

14. The reinforcing bar of claim 13, wherein only a portion of said longitudinal hole is filled with a resin matrix containing randomly oriented short reinforcing particles.

15. The reinforcing bar of claim 12, which contains a plurality of flattened areas.

16. The reinforcing bar of any of claims 1-15 having a plurality of raised surface dimples.

17. The reinforcing bar of claim 16 wherein said raised surface dimples are partially embedded particles of a thermoplastic or thermoset resin, a ceramic, a metal or a mineral.

18. The reinforcing bar of any of claims 1-17, wherein said thermoplastic resin is a blend of a depolymerizable and repolymerizable thermoplastic polyurethane or polyurea and a minor amount of a polystyrene, polyvinyl chloride, ethylene vinyl acetate, ethylene vinyl alcohol, polybutylene terephthalate, polyethylene terephthalate,

acrylonitrile-styrene-acrylic, ABS (acrylonitrile-butadiene-styrene), polycarbonate, polypropylene or aramid resin.

19. A reinforcing grid comprising a plurality of reinforcing bars according to any of claims 1, 2, or 4 that are interconnected to form a unitary grid structure.

20. A shear truss comprising a plurality of reinforcing bars according to any of claims 1, 2, or 4 that are interconnected to form a unitary shear truss structure.

21. The reinforcing bar of any of claim 1-10 and 11-18 that is substantially straight and includes an external coating that does not adhere to concrete.

22. The reinforcing bar of any of claims 2 or 4 which includes at least one external raised winding twisted around and traversing the length of the reinforcing bar which at least one winding being acomposite of a plurality of longitudinally oriented reinforcing fibers embedded in a matrix of a depolymerizable and repolymerizable thermoplastic resin.

23. A concrete structure comprising a reinforcing bar embedded in a concrete matrix, said reinforcing bar comprising a composite of a plurality of longitudinally oriented reinforcing fibers embedded in a matrix of a thermoplastic resin.

24. The concrete structure of claim 23, wherein the concrete matrix includes a cement or mortar, and a particulate filler.

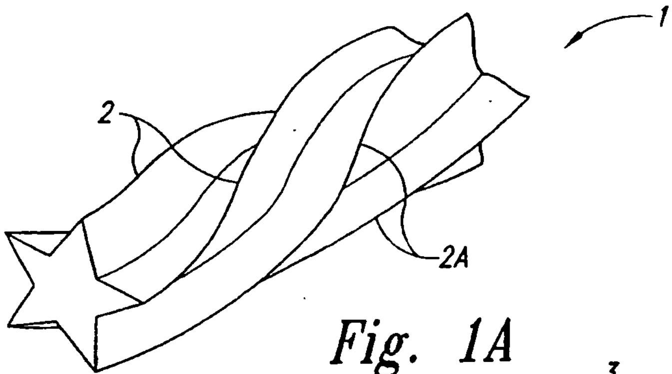

Fig. 1A

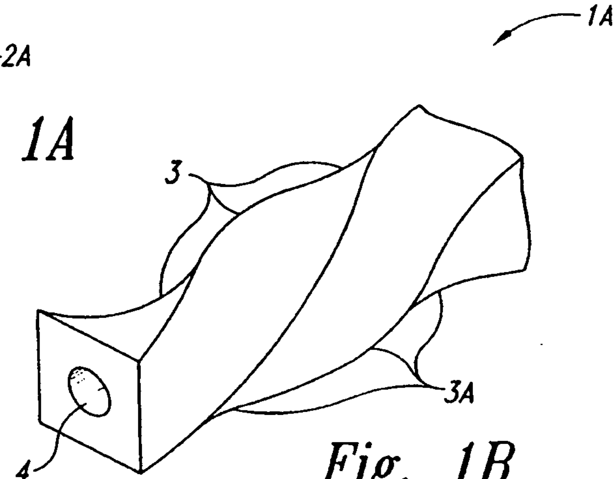

Fig. 1B

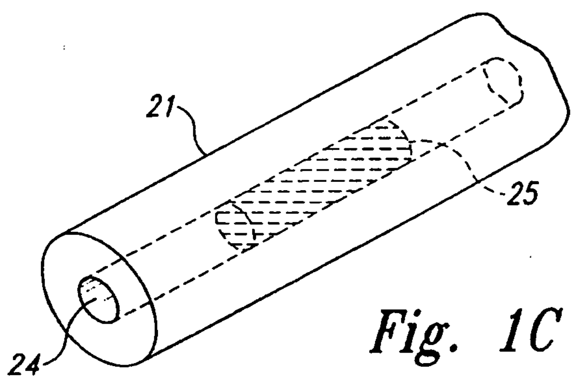

Fig. 1C

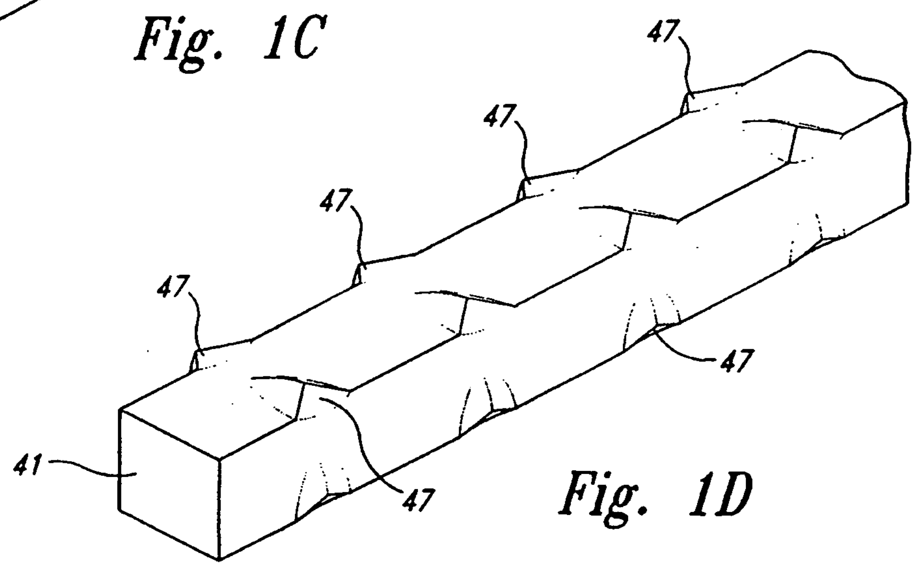

Fig. 1D

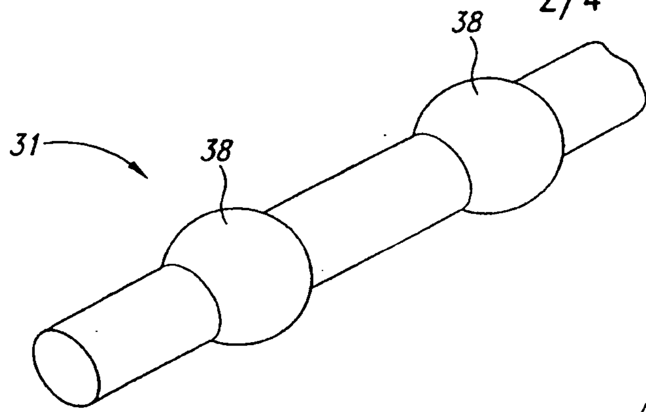

Fig. 1E

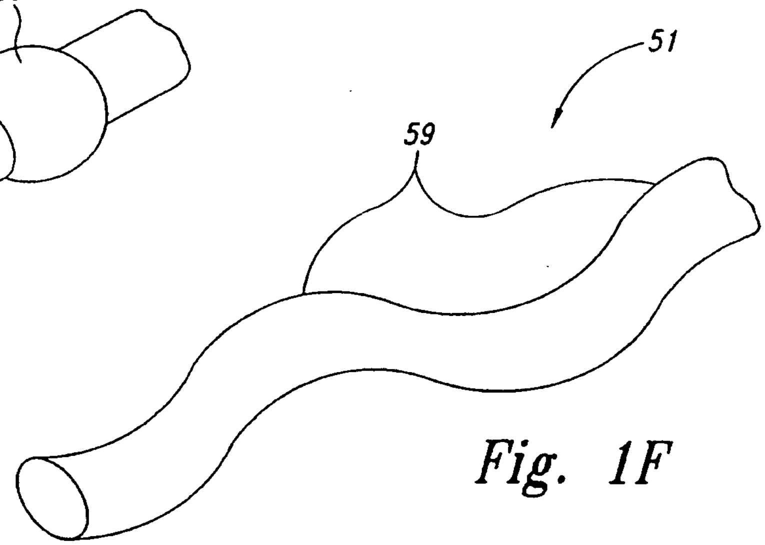

Fig. 1F

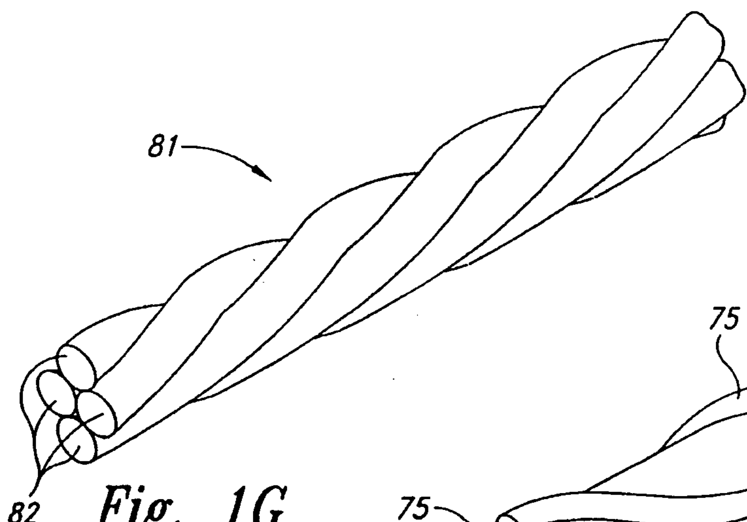

Fig. 1G

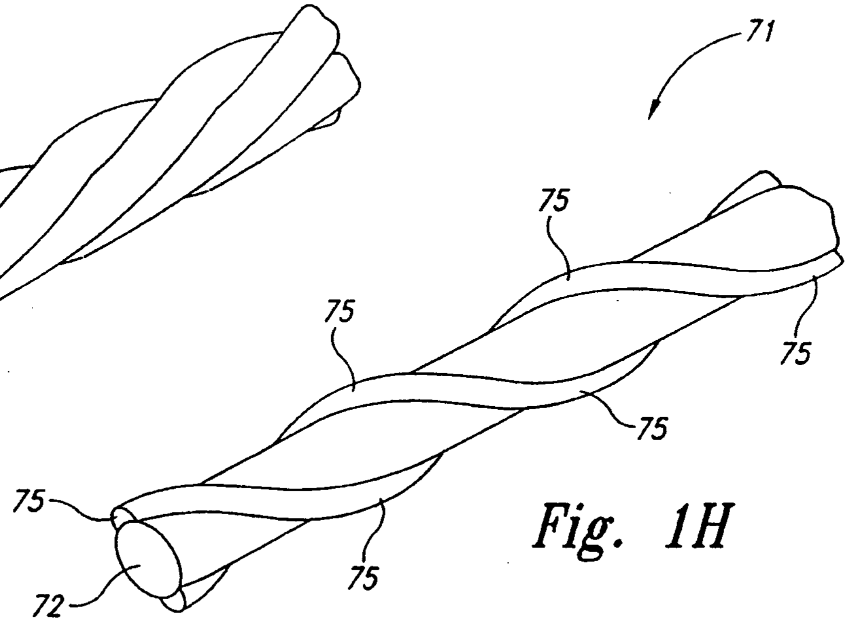

Fig. 1H

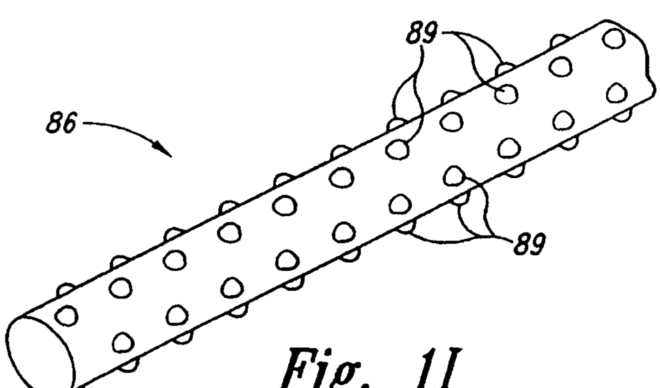

Fig. 1I

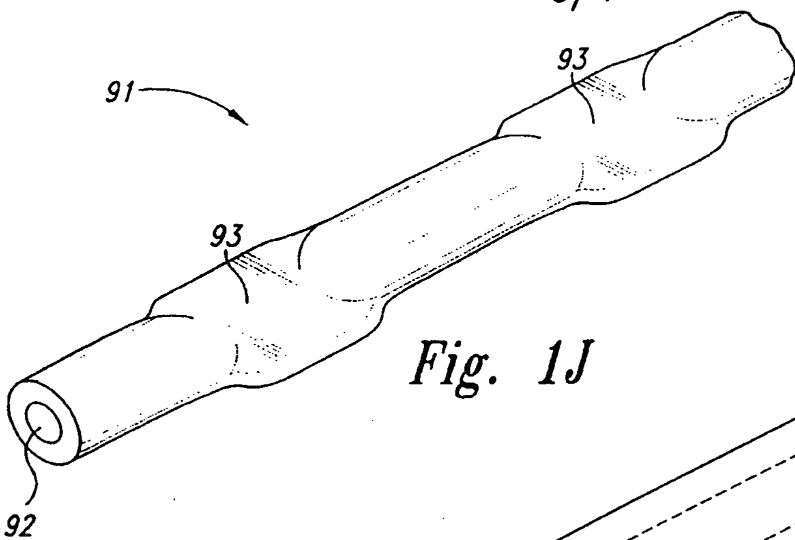

Fig. 1J

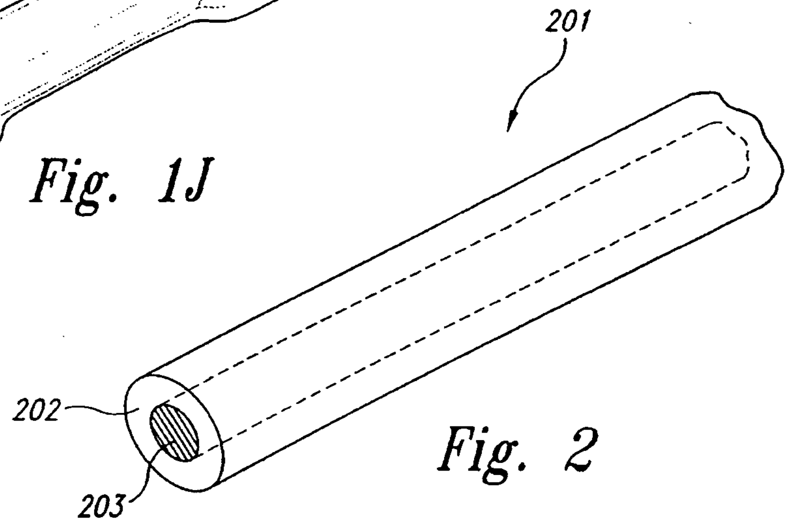

Fig. 2

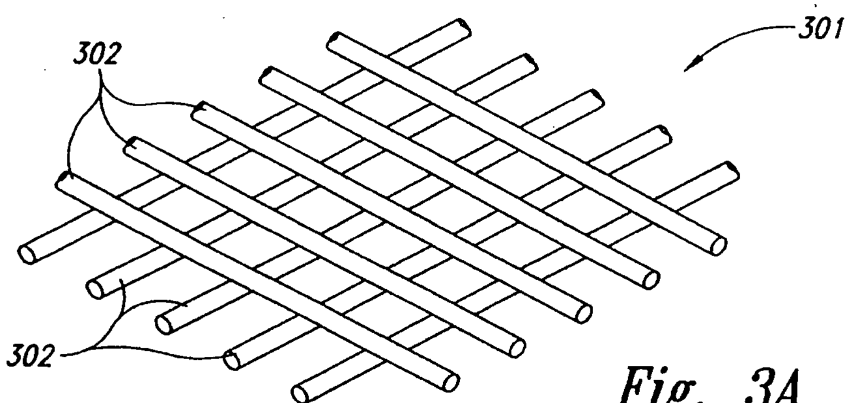

Fig. 3A

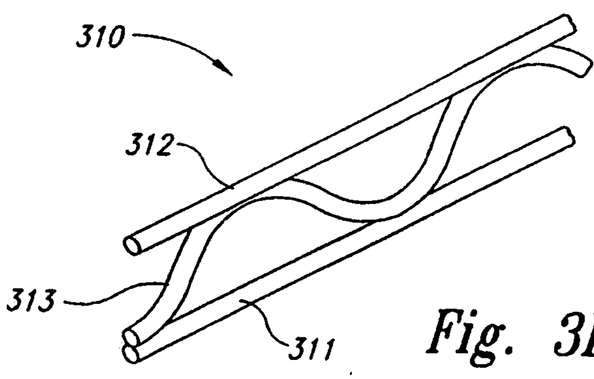

Fig. 3B

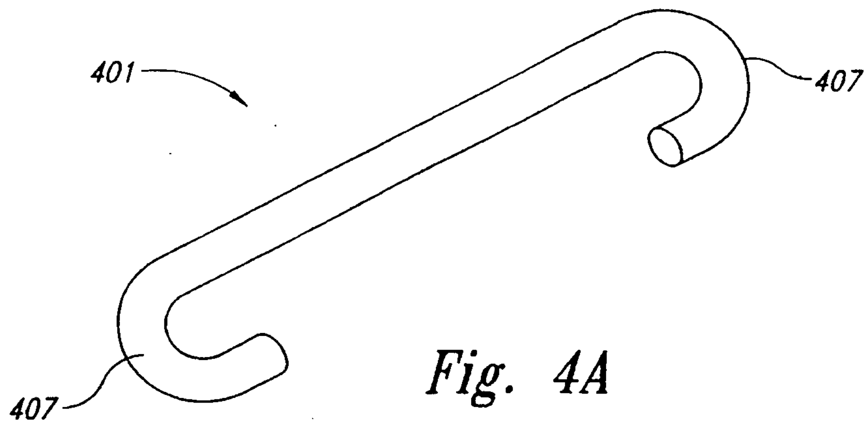

Fig. 4A

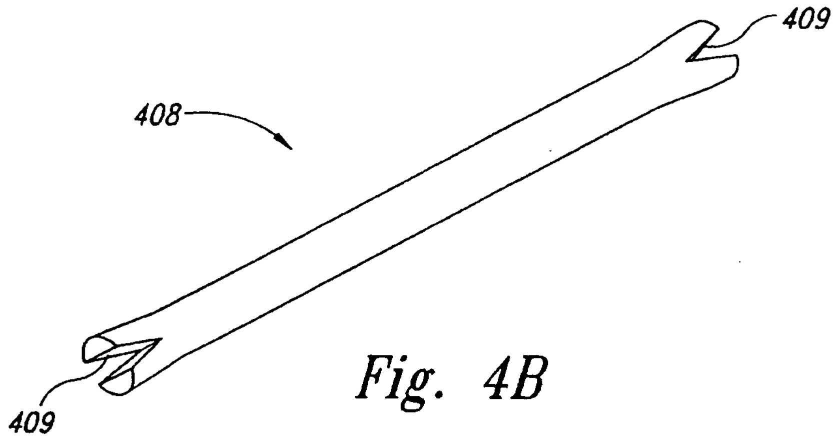

Fig. 4B

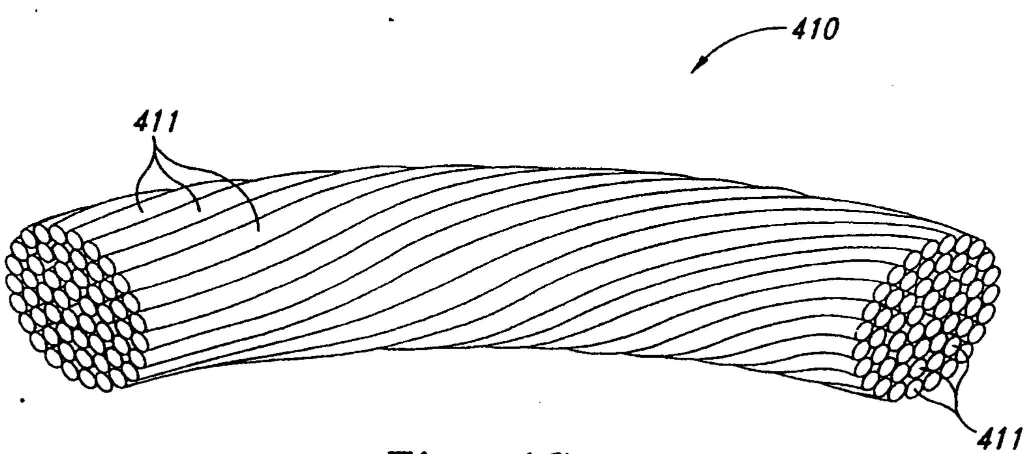

Fig. 4C

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 01/00533

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 E04C5/07

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 E04C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	US 5 891 560 A (EDWARDS CHRISTOPHER MICHAEL ET AL) 6 April 1999 (1999-04-06) column 3, line 8 -column 3, line 23 column 4, line 15 -column 4, line 31 column 4, line 48 -column 4, line 50 column 5, line 59 -column 5, line 61 column 6, line 12 -column 6, line 20 column 6, line 46 -column 6, line 50 column 6, line 60 -column 6, line 65 claim 1 ---	1,2,4-6, 18 3,7-9, 11-17, 19-24
Y	US 4 194 873 A (KILLMEYER CHARLES W) 25 March 1980 (1980-03-25) claim 1; figures 3-9 --- -/--	3,7,23, 24

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
7 March 2001	14/03/2001

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Hendrickx, X

Form PCT/ISA/210 (second sheet) (July 1992)

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 98 31891 A (CAMPLAS TECHNOLOGY ;WILLIAMS ANTHONY CAREY (GB)) 23 July 1998 (1998-07-23) claims 1-3,6,7,10; figures 1-4	8,23,24
Y	US 5 580 642 A (OKAMOTO TADASHI ET AL) 3 December 1996 (1996-12-03) claim 1; figures 1,4-9	8,23,24
Y	EP 0 774 552 A (KOMATSU MFG CO LTD ;KOMATSU PLASTICS INDUSTRY CO L (JP)) 21 May 1997 (1997-05-21) claims 1,6,7; figures 1,4,5	9,15,23,24
Y	US 5 362 542 A (OZAWA NOBUYUKI ET AL) 8 November 1994 (1994-11-08) claim 1; figures 1-3,9-11	11,23,24
Y	US 4 341 835 A (MACDOWELL JOHN F) 27 July 1982 (1982-07-27) column 2, line 24 -column 2, line 29 column 3, line 1 -column 3, line 7	12,23,24
Y	US 5 763 042 A (DOUGLASS NELSON H ET AL) 9 June 1998 (1998-06-09) column 3, line 6 -column 3, line 25 claims 1,17; figures 1-3	13,14,23,24
Y	WO 96 16792 A (APPLIED RES AUSTRALIA ;THICTHENER EDWARD PHILIP (AU); HASTWELL P J) 6 June 1996 (1996-06-06) page 9, paragraph 3 figures 2B-5	16,17
Y	FR 2 009 094 A (ABBUD KLINK SAMI) 30 January 1970 (1970-01-30) page 8, line 26 -page 9, line 10 figure 2	16,23,24
Y	US 4 648 224 A (KITTA TOSHIYUKI ET AL) 10 March 1987 (1987-03-10) claims 1-3; figures 1,2	16,17,23,24
Y	US 4 706 430 A (SUGITA MINORU ET AL) 17 November 1987 (1987-11-17) claims 1,4,5; figures 1-3,9-13	19,20,23,24
Y	US 5 763 043 A (PORTER JOHN F ET AL) 9 June 1998 (1998-06-09) abstract figures 4-8	19,23,24

-/--

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
Y	DE 33 36 765 A (HEIDENAU NETZ & SEIL VEB) 5 July 1984 (1984-07-05) page 3, paragraph 4 -page 3, paragraph 5 claims 1,2; figures 1-3	21,23,24
Y	US 5 182 064 A (ISHIZUKA HITOHARU ET AL) 26 January 1993 (1993-01-26) claim 1; figures 1,3	22-24
A	WO 89 00493 A (BROKEN HILL PTY CO LTD) 26 January 1989 (1989-01-26) page 5, line 34 -page 6, line 16 figures 7-10	10
A	US 4 379 870 A (MATSUMOTO HISASHI) 12 April 1983 (1983-04-12) figures 1-20	10
P,A	EP 0 994 223 A (CREDALI LINO) 19 April 2000 (2000-04-19) column 4, line 18 -column 4, line 39 figure 2	12-14

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5891560 A	06-04-1999	EP 0993487 A	19-04-2000
		WO 9901501 A	14-01-1999
		US 6165604 A	26-12-2000
US 4194873 A	25-03-1980	NONE	
WO 9831891 A	23-07-1998	EP 0892876 A	27-01-1999
		GB 2329199 A	17-03-1999
US 5580642 A	03-12-1996	JP 5269726 A	19-10-1993
EP 0774552 A	21-05-1997	JP 8042060 A	13-02-1996
		NO 970411 A	19-02-1997
		CA 2195418 A	15-02-1996
		WO 9604440 A	15-02-1996
US 5362542 A	08-11-1994	JP 6042112 A	15-02-1994
		CA 2092625 A	14-09-1993
		EP 0560362 A	15-09-1993
US 4341835 A	27-07-1982	BR 8107806 A	08-09-1982
		CA 1161984 A	07-02-1984
		DE 3151722 A	09-09-1982
		FR 2498590 A	30-07-1982
		GB 2092598 A,B	18-08-1982
		JP 57140365 A	30-08-1982
		SE 452151 B	16-11-1987
		SE 8200363 A	27-07-1982
US 5763042 A	09-06-1998	AU 683161 B	30-10-1997
		AU 2596995 A	25-01-1996
		BR 9508161 A	12-08-1997
		CA 2194093 A	11-01-1996
		EP 0769088 A	23-04-1997
		JP 10506691 T	30-06-1998
		WO 9600824 A	11-01-1996
		US 5702816 A	30-12-1997
		US 5650109 A	22-07-1997
		US 5851468 A	22-12-1998
WO 9616792 A	06-06-1996	AU 1188295 A	19-06-1996
FR 2009094 A	30-01-1970	DE 1925762 A	08-01-1970
US 4648224 A	10-03-1987	JP 1664880 C	19-05-1992
		JP 3030668 B	01-05-1991
		JP 60203761 A	15-10-1985
		CA 1242093 A	20-09-1988
US 4706430 A	17-11-1987	JP 1998920 C	08-12-1995
		JP 7006254 B	30-01-1995
		JP 62202157 A	05-09-1987
		JP 7100963 B	01-11-1995
		JP 62153449 A	08-07-1987
		AU 586378 B	06-07-1989
		AU 6104986 A	02-07-1987
		CA 1278699 A	08-01-1991
		CN 86105936 A,B	01-07-1987

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/US 01/00533

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 4706430 A		DE 3687345 A	04-02-1993
		DE 3687345 T	29-07-1993
		EP 0227207 A	01-07-1987
		KR 9108088 B	07-10-1991
		US 4819395 A	11-04-1989
US 5763043 A	09-06-1998	AT 161306 T	15-01-1998
		CA 2127577 A	09-01-1995
		DE 69407359 D	29-01-1998
		DE 69407359 T	02-07-1998
		DK 637658 T	02-02-1998
		EP 0637658 A	08-02-1995
		ES 2110659 T	16-02-1998
		HK 1005781 A	22-01-1999
		US 5552207 A	03-09-1996
		CA 2046021 A	06-01-1992
		EP 0464803 A	08-01-1992
DE 3336765 A	05-07-1984	DD 210102 A	30-05-1984
		HU 191907 B	28-04-1987
US 5182064 A	26-01-1993	JP 3218817 A	26-09-1991
		JP 6017075 B	09-03-1994
WO 8900493 A	26-01-1989	AU 2074588 A	13-02-1989
US 4379870 A	12-04-1983	JP 1429592 C	09-03-1988
		JP 55010423 A	24-01-1980
		JP 62028106 B	18-06-1987
		JP 1361539 C	30-01-1987
		JP 55015928 A	04-02-1980
		JP 61025669 B	17-06-1986
		JP 55085457 A	27-06-1980
		CA 1141914 A	01-03-1983
		CA 1147115 A	31-05-1983
		CH 650303 A	15-07-1985
		DE 2927435 A	24-01-1980
		FR 2430399 A	01-02-1980
		GB 2025841 A,B	30-01-1980
		US 4297414 A	27-10-1981
EP 0994223 A	19-04-2000	NONE	